Limits on inferring an effective rheology from the post-earthquake period using geodetic observations

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The deformation of the solid Earth can be described using a viscoelastic constitutive relation or rheology. While our knowledge of elastic moduli within the Earth's interiors is well constrained by seismological observations, there are limited opportunities to probe the viscous component of the constitutive relation. A current challenge is that the exact formulation of the viscous rheology of the crust-mantle system is itself not uniquely constrained i.e., multiple formulations (linear Burgers and power-law) are able to recreate geodetically observed kinematics of the earthquake cycle. Here we show that it is possible to discriminate between these popular rheological models, even with the limited observational time span of geodetic networks, using simple physics-based numerical inverse models. We first run a set of numerical simulations of periodic earthquake cycles as well as 2-event sequences for a 2-D strike-slip fault in a frictional-viscoelastic medium using *realistic* rheological parameter choices, and then predict the resulting surface displacement time series over a 20-year time window. We invert the synthetic surface displacements to obtain best-fit parameters for a simplified boundary element representation of each rheological model and compare the misfits. Linear Burgers and power-law rheologies are nearly indistinguishable when considering periodic events, but they can be distinguished using data from earthquake sequences when events are at least 0.2 units different in magnitude and greater than 1 year apart in time. However, estimating rheological parameters appears to result in non-unique solutions, even for the statistically superior model class. We discuss possible remedies to this. Additionally, we show that the rheologies we considered here display a strong dependence of the late inter-seismic locking depth on the depth of the model domain. Circumventing this issue presents a need for a transient rheology. Distinguishing between linear, power-law and possibly transient rheologies and estimating associated parameters is a step towards building better hazard models of regional seismicity and relative sea-level.